User's Guide to

C-MET's LTCC Fabrication Facility

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Contents

1. What is LTCC?

The Low Temperature Co-fired Ceramic (LTCC) is a multilayer interconnects fabrication process that uses glass-ceramic tapes and conducting pastes for preparing the circuits. The process ultimately produces multilayer ceramic circuits, quite similar to the multilayer printed circuit boards with solder-attached active and passive components on the outer surfaces, with some differences. The LTCC multilayer circuits are much denser and offer far better electrical properties. The use of glass-ceramic material allows reduced co-firing temperature to below 900^{o}C compared to the conventional ceramic firing temperatures. This permits use of Ag, Au and their alloys for interconnections which offer better stability during processing and are better conductors. Such low firing temperature also allows use of other standard functional materials (such as, those for resistors, capacitor dielectrics *etc*) within the structures, which is a major advantage. By virtue of such capabilities, LTCC enjoys significant advantages in terms of package size, reliability, cost and manufacturability over the other multilayer circuit fabrication processes. ***Figure 1.1*** presents a schematic representation of typical LTCC package.

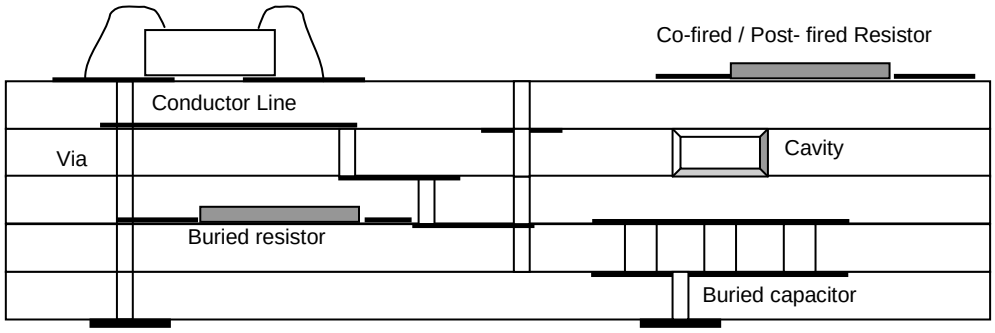

Figure 1.1: Schematic of LTCC Structure showing its capability to integrate with active devices

In summary, the specific advantages of LTCC can be listed as below:

- Reliable packaging due to ceramic processing
- Multilayer or 3D circuit capability which is virtually unlimited
- Low dielectric loss and better control over dielectric properties
- HF capabilities in microwave and millimeter wave frequency range
- High density integration due to smaller via and inclusion of buried passive elements

- Capability of packaging of Si chips along with any other technology devices
- Hermetic sealing capability
- Can handle fluidic, optical, mechanical and electrical signals simultaneously
- Microsystems - devices can be packaged as well as fabricated in LTCC
- Close thermal expansion coefficient to Si, GaAs allowing direct attachment of chips
- Compatibility with flip chip, wire bonding and SMT processes

The following may be listed as disadvantages of LTCC, although not all would matter in an intended application:

- High shrinkage after co-firing and its tolerance cause process difficulties
- Limited range and high tolerance for buried passive components due to materials limitations
- Higher cost than polymeric packages
- Low thermal conductivity of tapes as compared to ceramic materials
- Non-flexible packages

Fortunately, there are ways to overcome some of the disadvantages. For example, the heat can be routed through thermal via to the outer world, thereby circumventing the difficulty of relatively low thermal conductivity. Next, there are some special processing methods which can make the shrinkage as low as zero in X-Y direction. More discussion about some of the process and applications related issues can be found further in this document.

2. LTCC Fabrication Process and Materials

The LTCC green tapes are prepared by uniformly casting the inorganic powder into polymeric materials using tape-casting technique. The slurry of the casting material is composed of glass-ceramic mixture or composites in binders and organic solvent. This as-prepared slurry is cast to obtain glass/ceramic 'green' tape and is put together over a Mylar support. These tapes are now commercially available.

The circuit/ package preparation process starts with cutting of green tape to the required processing size and pre-baking at a specified temperature. This step is, however, not mandatory. After pre-conditioning of tapes, the package fabrication is initiated by preparing via holes, cavities and alignment holes on each single, individual layer, separately. The via holes are usually prepared by either mechanical punching, or laser cutting process and the diameter varies typically between ~100μm and 250μm. Same processes are used for creating cavities, which may vary from a few mm to a few 10's of mm in size, depending upon the design. The via are intended to be used as electrical connections.

Between layers are then filled with silver or gold paste, either by stencil printing method or by pressurizing the paste into the via holes. The stencil printing is done using a hard polymer squeeze while vacuum is applied below the sample. Once via are filled, usual thick film screen printing is then employed to print metallization layer and buried passives. The minimum line width of the printed conductors is usually about 100μm. Each single layer then passes through an optical inspection. Next, all such individually processed layers are aligned with help of registration pins, and stacked after removing the supporting mylar sheet. This method gives registration accuracy within 20μm. Automatic alignment is also employed sometimes, which gives slightly better alignment accuracy of about 10μm. After cutting off the registration area, whose utility is now over, the stacks are laminated using uni-axial heated press or an Isostatic laminator. The latter process is usually preferred due to its ability to retain cavity and via shapes. The individual circuits on the tiles are then singulated and co-fired at 850-900°C peak temperature following the manufacturer-recommended firing cycle. Sometimes, singulation is done after co-firing using diamond wheel cutting machine. The main

characteristic of sintered LTCC package is its all round shrinkage. Free or un-constrained sintering offers approximately 12-16 ± 0.3% and 15-25 ± 0.5 % shrinkage in X/Y and Z-direction respectively, depending on the composites used for preparation of LTCC green tape. The integrated LTCC substrate is then available for post-fire processing, which may include usual print-fire sequences for brazing, attachment of external components, BGA preparation *etc*. After the completion of all such processing, the substrate is ready for chip attachment and sealing. ***Figure 2.1*** presents the common process sequence for the preparation of LTCC structures.

Commercially, different types of tape systems are available, and there are a good number of manufacturers. DuPont, ESL, Ferro, Hearaus, Nikko, and Northrop Grumman, are amongst the representative names. All the commercial products are usually having similar properties, with differences in their dielectric constant, loss tangent, thickness and shrinkage. A partial list of commercial tape systems is presented in ***Table 2.1***.

One important point regarding LTCC materials is worth mentioning. All the commercial LTCC tapes have to be used with the compatible pastes or tapes made available by the same manufacturer. Here, by compatibility one mean that the shrinkage and 'materials interaction' properties (especially during firing) have to be tailored to match with each other. Therefore, due to the uncertainty about compatibility issues and thus, the final properties, mixing of materials system from different manufacturers is generally avoided.

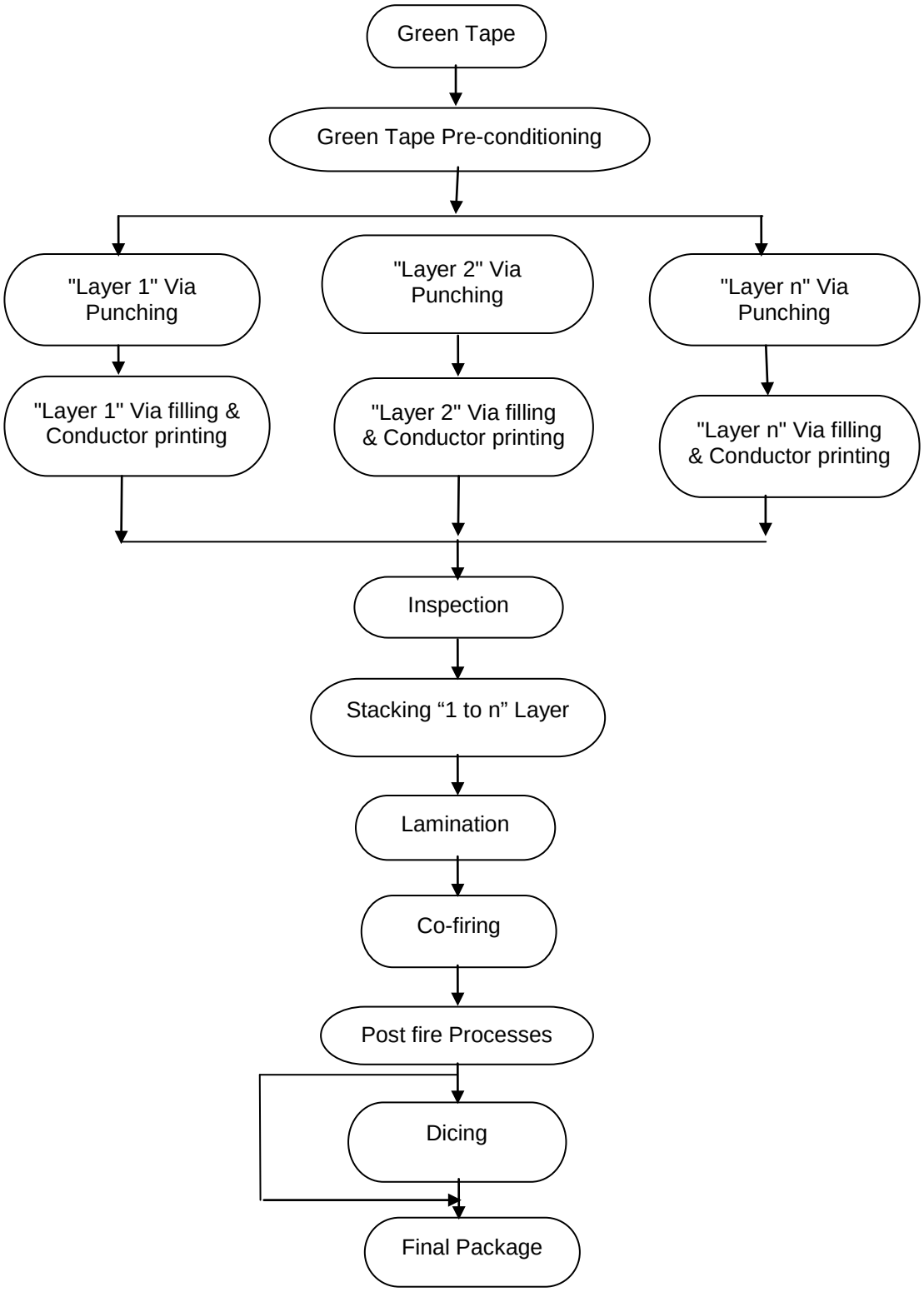

Figure 2.1: Process steps for manufacturing of LTCC modules

PROPERTY	DuPont 951	FERRO A6M	FERRO A6-B	EMCA T8800	HERA-TAPE CT700	Motorola T2000	DuPont 943
Colour	Blue	White	Black	Blue	Blue	White	Blue
Available Fired Thickness (Mils)	3.7, 5.2, 8.2	3.7, 7.4	3.3,6.7	3.5-15	3.6, 5.7, 7.9	3.8	4.5
Dielectric Constant (K)	7.8	5.9	6.5	7.2	7.9	9.1	7.5
Loss Tangent	0.15%	<0.2%	<0.5%	<0.2%	<0.2%	<0.3%	<0.1%
µ-wave Insertion Loss (dB/in) @ 10GHz	-	.18	<.35	<.5	-	-	0.12
Insulation Resistance	$>10^{12}$ Ohms	$>10^{12}$ Ohms	$>10^{12}$ Ohms	$>10^{12}$ Ohms	$>10^{12}$ Ohms	-	$>2x10^{12}$ Ohms
Breakdown Voltage	>1000 V/Mil	>900 V/Mil	>1000 V/Mil	>1000 V/Mil	>1000 V/Mil	-	>1100 V/Mil
Electrolytic Leak Current	-	<1 µ-amp/cm^2	<1 µ-amp/cm^2	-	-	-	-
Flexural Strength (kpsi) (3 point test method)	28.3	17.1	17.1	40.6	-	36	33.4
Young's Modulus (kpsi)	15	12	12	27	-	-	-
Poisson Ratio	.17	-	-	-	-	-	-
Fired Density (gm/cc)	3.1	2.5	2.5	3.06	3.1	3.13	3.2
TCE (ppm/°C)	5.9	7.5	9-10	6.0	6.7	5.6	6.0
Surface Roughness	<10 µ in	<15 µ in	<15 µ in	<15 µ in	<22 µ in	-	-
Camber	Conforms to setter						
X,Y Shrinkage	13±.2%	15±.2%	14.5±.2%	12±.2%	15±.2%	10.9%	9.5±.3%
Z Shrinkage	15±.5%	25±.5%	35±.5%	14±.5%	25±.5%	14.7%	10.3±.5%
Metallization	Au/Ag – Ag -Au	Au/Ag – Ag -Au	Au/Ag – Ag -Au	Au/Ag – Ag -Au	Au/Ag – Ag - Au	Au/Ag – Ag -Au	Au/Ag - Ag -Au

Table 2.1: Tape properties of various LTCC tape manufacturers

3. C-MET Materials Selection and Process Choices

As the previous section briefly describes, the generic LTCC process offers several choices at individual process steps. Likewise, one has to choose from a host of materials systems that are commercially available. This section provides a brief description of such choices made by C-MET while setting up the LTCC process, and reasons behind making certain choices.

3.1 Materials Selection

The selection of the tape system and its manufacturer has to be done carefully, depending upon the requirements of the targeted applications. For C-MET the choice of applications is wide, ranging from devices, device packaging, HF circuits, biomedical applications etc. Therefore, a tape system that is most suitable for all the possible applications was required to be selected. C-MET has presently chosen the DuPont 951 tape system for its LTCC operations because of its versatility, wide acceptance and availability of a wide range of materials for buried components, brazing *etc*. Additionally, this tape system provides option of Ag, Au and mixed metal system for the conductor fabrication. Further, the DuPont materials are easily available in India. ***Annexure-1*** provides the list of complete set materials available for the 951 Green Tape system along with their intended application.

Amongst the available materials with the 951 Green Tape systems, C-MET usually keeps stock of the Ag based materials, along with the Au based wire bondable conductor paste. C-MET also keeps the brazing and some low-value resistor materials. ***Table 3.1.1*** provides the complete list of materials usually available ex-stock at C-MET. Other compatible materials are purchase as and when need arises.

Material No.	Material type
Green Tapes	
951 PX	250 micron green tape
951 PT	100 micron green tape
951 C2	50 micron green tape
Pastes	
6141	Conductor Paste for via filling
6142D	Inner Conductor Paste
6146	Outer Conductor Paste
CF011	Resister Paste
6135D	Solderable conductor Paste(Post fire)
6138	Outer Conductor Paste
QQ550	Encapsulant Paste
4195	Encapsulant Paste
CF021	Resister Paste
5092 D	Resister Paste
9615	Dielectric Paste
5081	Conductor Paste (adhesive brazing)
5082	Conuctor Paste (barrier brazing)
5742	Solderable conductor paste
5087	Brazing Conductor paste
Post fire Soldering ,Sealing ,brazing & BGA pair attachment material	
90Pb-10Sn	Soldering Paste (Type IV)
99Sn-1Sb	Soldering Paste(Type III)
63Sn-37Pb	Soldering Paste
Solder Ribbon	96.5Sn-3.5Ag (1*0.004)
Solder Preforms	96.5Sn-3.5Ag [(2*0.512*0.413)*0.004]
Solder Spheres for BGA	90Pb-10Sn (0.030mm dia.)
Kovar Pins	0.45mm dia.,0.85mm head dia.,10mm length Ni/Au Plated

Table 3.1.1: LTCC materials usually available at C-MET. Other materials in this tape system can be purchased specifically for a particular implementation

3.2 Specific Process Choices

C-MET has also made her own choices for processes. Firstly, C-MET chose the about 6×6″ tape format providing 4×4″ tile area for circuit fabrication. This aspect is based upon the available formats at the time of selection, the size expectations for various applications and the cost of equipment for processing these tapes. The aim of the facility of being a "Prototyping Centre" for LTCC, was the guiding factor. ***Table 3.2.1*** provides details of available process choices for each process, the choice made by C-MET and the reasons of such selection. ***Annexure–I*** provides list of equipment used for LTCC process along with their important features and specifications.

Sr	Process	Process Options	C-MET Choice	Remarks
1	Design	• Standard CAD tools • Specialized LTCC design software	Standard CAD tool and Specialized LTCC design software	Standard CAD tool is useful in designing packages, but only the Specialized LTCC design software can handle large number of interconnects dense circuits and layers with Automatic DRC
2	Tape shaping	• Purchase cut sheets • Buy roll-cutting machine	Purchase cut sheets	Saves investment on blanking machine
3	Via formation	• Laser punching • Programmable punching	LASER punching and Programmable punching	LASER punching allows better flexibility in via sizes.
4	Inspection	• Microscope • Automated Optical Inspection	Microscope and Automated Optical Inspection	Opening of via and via edge quality etc can be verified. The punched design can be directly verified with the original design using AOI
5	Via filling	• Pressurized chamber • Stencil printing	Pressurized chamber and Stencil Printing	Flexibility of process Availability of Screen/stencil printer
6	Conductor formation	• Screen printing	Screen printing	---
7	Stacking	• Automatic video alignment • Pin-based alignment	Automatic alignment and Pin-based alignment with auto-stacking	Better alignment accuracy available with automatic alignment
8	Stack shaping	• Heated blade	Heated blade	---

9	Open or buried cavity formation	• Laser cutting • CNC milling • Punching using power press	LASER cutting, CNC milling and punching using power press	Punching of various geometries/ shapes of various sizes is possible with the help of LASER & CNC. Power press with die-punch assembly can be used for high volumes
10	Lamination	• Parallel plate lamination • Iso-static lamination	Parallel plate lamination and Iso-static lamination	Parallel plate lamination provides option for laminates without cavities, Isostatic lamination gives better quality, ability to prepare buried and closed cavities
11	Singulation	• Green stage cutting • Post-fired cutting	Green stage cutting and post-fired cutting	Both have individual advantages depending on the end product requirement.
12	Co-firing	• Free firing • Constrained firing • Press-sintering	Free firing and press-sintering	Both choices expands flexibility
13	Resistor trimming	• LASER trimming • Buried resistor trimming	Both, LASER and Buried trimming	Provides complete flexibility to the designer for placing low tolerance resistors
14	Contact formation	• BGA formation • Pin attachment (KOVAR) • Wire bonding	BGA formation and Pin attachment	Capability to have large number of interconnects
15	Tube attachment	• Soldering • Brazing	Soldering and brazing	Provides complete flexibility to tube attachment
16	Chip attachment and connections	• Filp-chip bonding / Face-up bonding	---	Not available yet
17	Hermetic Sealing	• Seam sealing • Solder sealing • LASER sealing	Seam and solder sealing	LASER sealing is required in only certain applications, such as using SS lids etc. The two choices made here cover most other applications
18	Inspection after firing	• X-ray inspection	X-ray tomography	In-situ inspection of the fired samples. Non-destructive inspection is possible for alignment verification or other issues.

Table 3.2.1: Process choices made by C-MET

3.3 C-MET's Current Process Limitations

The description in ***Table 3.2.1*** above indicates that C-MET has already established a full-fledged LTCC processes for most of multilayer LTCC design can be implemented. With the availability of such facilities and processes, there are a very few limitations, which are listed in the following.

- *Passive and active device placement and attachment:* Presently, the LTCC multilayer circuits or packages can be fabricated, but circuit or package cannot be assembled / populated with passive / active components as C-MET does not have any SMT pick and place machines and chip attachment facilities.
- *Laser Sealing:* Presently only seam and solder sealing are available. LASER sealing is useful for applications such as pressure sensors, where stainless steel may be required for sealing.

Recently, new, advanced machines have been inducted in C-MET's facility, which has significantly eliminated many of the limitations.

Annexure I

Present Equipments & Capabilities

Following is a short description of the equipment added to the existing facility, giving its important specifications, capabilities and manufacturer.

1. **Via Puncher**
    - Make: Keko, Slovenia
    - Punches green ceramic tapes with or without carrier film
    - Easy CAD-CAM programming via DXF
    - Punching area: up to 5" x 5"
    - Punching capabilities: min 80 µm & max. 5mm
    - C-MET's Present Capabilities:
        Circular punch: 200µm, 1mm, less than 1mm (variable) and 3mm
        Square punch: 2mm
    - Alignment to previous punching
2. **Screen Printer with Visual Aligner**
    - Make: DEK-J, Japan
    - Printing by Stencil and Screen printing method
    - SS made screens and stencils for X-Y printing and Z filling respectively
    - CCD camera equipped visual aligner for better alignment and accuracy
3. **Green Ceramic Foil Stacker**
    - Make: Keko, Slovenia
    - Stacking of printed and via filled Green LTCC tape layers on carrier blocks to form multilayered structure
    - Layer alignment by positioning pins
    - Three different stacks can be processed simultaneously
    - Two parallel hot plates pressing technique (temperature 120°C max.)
    - Pressing surface area: 160 × 160 mm
    - Pressing force: 200 kN max.; adjustable
4. **Green Stack Cutter**
    - Make: Keko, Slovenia
    - Cutting of green ceramic stacks into individual components
    - Cutting by SS or Silicon carbide blade with heating option for smooth cut
    - 2 CCD cameras for alignment mark detection
    - High precision heated vacuum table with X, Y and θ motion

5. Isostatic Laminator

- Make: Keko, Slovenia
- Thermal pressing up to 90°C of ceramic stacks in distilled water
- Pressure up to 50Mpa can be given
- Presses 4" × 4" stack
- Programmable pressing cycle time up to 50 minutes

6. Programmable Batch furnace

- Make: ATV, Germany
- Furnace temperature up to 1000°C
- Programming in 100 steps possible
- Max. 3 process gas connection and vacuum firing possible with pre-defined time across available 100 steps
- High cooling and heating ramp rate

7. High Temperature Reflow Oven

- Make: Sikama Falcon 5/C, USA
- Hot stage multi-purpose reflow oven to melt high temperature solder up to 400°C
- Appropriate gas flow

8. Mask Aligner & Exposure System

- Make: ABM, USA
- 1000 watt near UV light source with expose time ranging from 0.1 to 999.9 seconds
- Alignment tooling with standard X, Y and θ motion
- Dual CCD camera for alignment system
- Vacuum chuck to hold 4" sample
- Accuracy: ± 1µm

9. Package Seam Sealing Unit

- Make: Unitek Benchmark, USA
- Hermetically seam welds and solder seals ceramics, SS, Kovar™ and other metal packages from 3.17 mm to 203 mm to MIL SPEC 883E
- Positioning accuracy of ±0.038mm
- High speed welding up to 38mm/s

10. Thickness Monitoring Unit

- Make: Taylor Hobson, UK
- Thickness profiling by three gauge

  CLA confocal gauge: 300µm to 3mm

LASER gauge: up to 10mm range
Inductive gauge: range of 2.5 mm

- 3D profiling

11. Manual Probe Station

- Make: Cascade Microtech, USA
- DC prober with microwave probes
- Equipped with stereo microscope

12. Shear Strength Tester

DAGE, Singapore, make shear strength tester with only ball shear option is available presently.

13. Underfill Dispenser

DIMA, The Netherlands, make Automatic programmable dispenser. Dotmaster for high and low viscous solder paste, adhesive, underfill and glob top applications with maximum dispensing area of 320 × 420 mm.

14. Pulse Plating Power Supply

Pulse plating power supply specially designed for electroplating of solder for BGA preparations having forward and reverse current mode.

15. Lapping and Polishing Machine

Speedfam make, Single side lapping and polishing machine. Sample size max 50 mm.

16. Millipore Water Purification System

10-15MΩ and 18 MΩ water @ 3 and 10 litres per hour

17. Diamond Wheel Cutter

Specially designed for cutting of fired LTCC/ ceramic structures (for inspection only)

18. Design and Analysis Software

- Design software: AutoCAD and Ganymede, IMST Germany
- Analysis software: Ganymede with Empire full 3D-EM field simulator based on FDTD. Simulation of microwave passive components and many more utilities packaged with this software.

19. Belt Furnace

- Make: BTU, USA
- Thick film, Belt type firing furnace up to 1000° C
- Appropriate gas flow

20. Vacuum Evaporation Unit

- Make: Hind Hi Vacuum, India

21. Stereo Microscope

- Make: Olympus, Japan
- Digital Photographic attachment with measurement software
- Computer interfacing

22. Potentiostat - Galvanostat

- Make: Autolab, USA
- Includes GPES and FRA analysis

23. Measuring Microscope

- Make: Nikon Corporation, Japan
- Up to 1000 X magnification
- Digital Photographic attachment with measurement software

24. Specialized Design Software

- Make: Electronic Packaging Designer (EPD) by CAD Design Software (CDS)
- Large Via density: up to 2500/sq. inch
- BGA designing and placement
- 3D package development
- DRC & Advanced DRC (ADRC) with unlimited checking capability and configurable design rules definitions
- Auto as well as Manual Routing option with online DRC
- Supports popular output formats like GerbOut, DXF; which are needed to make Gerber, Punch and Nibble files for LTCC fab. process

25. Measuring Microscope

- Make: Olympus Corporation, Japan
- Up to 500 x magnification
- Sample Stage: 170x170 mm with 100 mm travel in X & Y
- Digital Photographic attachment with measurement & analysis software

26. LASER Micromachining and Trimming Machine

- Make: Process Photonics, Canada
- Nd-YAG (355nm) with focused beam diameter 15µm and 7W power

- Micromachining via and cuts of various shapes and size of green tapes and stacks, engraving / scribing over fired LTCC
- Resistance trimming of thin and thick film resistors; in the range 10 Ω to 10 MΩ, with better than 1% trimming tolerance.

27. CNC Milling Machine

- Make: LPKF, Germany
- Materials: Glass-ceramic tapes with thickness varying from 25 µm to 700 µm and dimensions up to 170 × 170 mm and pressed and laminated stacks of such tapes (170 × 170 mm) with thickness up to 10 mm
- Accuracy of position, shape and dimensions and control: ±5 µm
- Vacuum Holding Arrangements
- No use of coolant for un-fired tapes and stacks
- Programmed drilling using 'DXF' files

28. Hydraulic Press – for Die Punching

- A hydro-pneumatic power press for punching out portions of LTCC tapes / stacks with the help of a precision die-punch-stripper assembly
- LTCC tapes and stacks of size 6.625" with thickness from 300 µm to 8 mm

29. Automated Optical Inspection

- Make: SIBCO BV, The Netherlands
- Samples: LTCC tapes with via, filled via and screen printed green LTCC tapes, (up to 7", screens and stencils with frame size 320 x 320 mm)
- Illumination from front and back with appropriate wavelength and intensity for useful contrast
- pixel size 5µm or lower
- Faults can be detected (Before screen printing): Scratches, cracks, contamination and debris on blank-unprocessed tapes, missing via, channels, improper shapes of channel and cuts in the un-fired tapes, invalid distances between via, channels, unintentional via or structures, improper dimensions of via, channels or any other cuttings
- Faults can be detected after printing: Missing tracks, Interrupted tracks, bridges / voids, missing pads, invalid dimensions and shapes of lines, pads, filled via or any other printed shape, invalid distances between interconnects, pads, filled via, passive structures, unintentional

interconnects, pads, passive structures, fault finding like cracks, contamination and debris on processed tapes

30. Pressurized Via Filling

- Pressure: up to 6 Bar
- Porous Plate for holding and vacuum pull
- Filling capability: up to 100µm via

31. Screen Cleaning Machine

- Make: Sonictron Sdn. Bhd, Malaysia
- Ultrasonic generator: 1500-2000W at 40kHz
- Ultrasonic cavitations in IPA bath followed by CDA blow for drying
- Capable of cleaning printing screens and stencils made of silk / stainless steel cloths or stainless steel sheets, frame size from 300 x 300 mm to 750 x 750mm

32. Automated Stacking Machine with LASER Alignment

- Stacking using LASER peak detection technique
- Alignment accuracy: 15µm
- Automatic alignment and stacking process

33. Press Sinter Machine

- Make: Keje Thermoweld Equipments Pvt. Ltd., Pune
- Samples: Several 4″ or 6″ square LTCC unfired stacks with thickness up to 10 mm
- Press: up to 5kN, min. 100N, accuracy ±1%; max. stroke 150 mm
- Furnace: up to 1200^{o}C; control accuracy ±0.5%; uniformity ±3^{o}C;
- Atmosphere: controllable gas line through MFC for air, and other two gas lines for N2 / other gas
- PLC control: Full recipe programmability of pressure, atmosphere and temperature

34. Wire Bonder

- Make: HYBOND Inc., USA
- Bonding: Wedge-wedge, Ball-wedge, bumping, ribbon; 90^{o} deep access (12 mm)
- Bonding mechanisms: Ultrasonic, thermosonic, wedge

- Bond force: Variable between 15gf to 120gf
- X-Y Stage: 15×15mm or more; mouse ratio 1:6
- Z control: motorized, with 50mm travel; 1µm step resolution
- Wires: Capability to bond Al and Au wires in the range 17-25µm and ribbons about 25×250µm
- Viewing: 7-40X stereo zoom microscope or CCD camera with TFT viewing panel with fiber optic / LED illuminator

35. Buried Resistance Trimmer

- Make: Shalom Instruments, Bangalore
- Resistance range: 1-100 kΩ
- Trimming: Up to 30% higher; accuracy settable up to 0.5%
- Probe station: Two probes; for 4 × 4″ area samples; pad size min. 200 × 200 µm, min. distance between pads 150 µm
- Control and software: PC based, menu driven with easy Graphic User Interface (GUI)

36. Dicing Machine

- Make: Advanced Dicing Technologies Ltd., Israel
- Samples: Si, Glass-ceramic and Ceramic samples up to 7 × 7″ with hardness 8-10 Gpa
- Sample holding: Samples stuck on glass / UV tapes and held by vacuum
- Cutting range and speed: 200 mm; 300 mm/s or more
- Cutting depth parameters: Stroke up to 30 mm or more, accuracy 1 µm, resolution 0.2 µm
- θ-axis maximum rotation angle: 350 deg or more
- Indexing parameters: Range 200mm, positioning accuracy 3µm
- Max. chipping: 25 and 40 µm for samples up to 2 and 6 mm thickness
- Cutting blade: Resin bonded diamond (45µm grit) wheel; Dia. 4-5″
- Spindle and drives: 30000 rpm or more, air bearing, brushless dc motor drive & lead screws in cutting direction; stepper motor with lead screws in indexing direction
- Alignment: With fiducials; accuracy 1µm

37. X-Ray Imaging Machine

- Make: Xradia Inc, USA
- X-Ray tube: Standard reflection type closed tube, operating voltage from 40-150kV, Tungsten target, spot size <5µm that does not limit the final resolution
- Submicron resolution: <1µm
- Spatial resolution: < 1.3µm; final resolution is independent of spot size, sample working distance or sample size
- Sample size and holder: Large samples size with width 300mm & height 500mm, weight up to 15kg; 4-axes manipulation; 360^{o} scanning
- Detector: Combination of sintilator and visual range optics for high contrast; Phase enhanced detector High contrast images possible of low atomic number materials such as Si or GaAs
- High speed data acquisition: 1024 slices from 181 projections < 3 min
- Continuous operation through automated multiple point tomography and repetitive scanning
- X-ray leakage less than < 1 µSv/hr

38. Sputtering Machine

- Make: Milman Thin Film Systems Pvt. Ltd.
- RF / DC Magnetron System
- Two Target
- Substrate size of 6"
- Uniformity: ±5%